

INTEGRATION OF MODELS & SIMULATIONS INTO THE EVALUATION OF THEATER MISSILE DEFENSE BATTLE MANAGEMENT, COMMAND, CONTROL AND COMMUNICATIONS (BM/C3)

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ABSTRACT: *Models and simulations (M&S) provide an analytical representation of complex systems that can be used in the evaluation of those systems in their operating environment. M&S, combined with other test methods such as Hardware-in-the-Loop Tests (HWILTs) and live test events, form a very powerful and valuable tool for the test and evaluation of complex systems. The incorporation of M&S allows the test program to be better focused on the critical evaluation areas. The early use of M&S in the system analysis, requirements definition, as well as system test and evaluation provides for a more comprehensive system engineering process. This paper presents a strategy for the integration and use of models and simulations (M&S) in a complex Battle Management Command, Control and Communications (BM/C3) Test and Evaluation (T&E) Program. M&S are needed to assess the contribution of BM/C3 to the interoperability of various missile defense systems operating in a Family of Systems (FoS) context in a theater of operations. Models and simulations will be incorporated into the TMD FoS T&E program using the principles of the Simulation Test and Evaluation Process (STEP). FoS T&E will be conducted to demonstrate program*

development and system performance throughout the life cycle of the FoS. Analysis will be the primary evaluation tool in the early phase of each increment. M&S will be used in pre-test planning and prediction as well as post-test analysis. FoS level exercises will be conducted to assess the interoperability and performance of the FoS. Based on data gathered from the live events, M&S will be used to assist in model V&V activities. This model-test-model paradigm will be repeated throughout the development and evaluation efforts.

1. INTRODUCTION

This paper presents a strategy for the integration and use of models and simulations (M&S) in the Theater Missile Defense (TMD) Family of Systems (FoS) Test and Evaluation (T&E) Program. M&S are needed to assess the interoperability of the various TMD weapons systems and Command and Control (C2) centers operating in a FoS context throughout a theater of operations.

T&E is the FoS assessment process that provides the necessary information to demonstrate an integrated FoS capability, identify and define interoperability problems, assess FoS status, and obtain data to validate and refine the models and simulations. Models and simulations provide an analytical representation of complex systems that can be used in the evaluation of TMD systems in their operating environment. M&S, combined with other test methods such as Hardware-in-the-Loop Tests (HWILTs) and live test events, form a powerful tool for the test and evaluation of complex systems.

M&S will be incorporated into the T&E program to provide the opportunity to aid in event planning, assess those objectives that cannot be tested in a live environment, minimize or reduce risk of live test events, and increase the tester's statistical confidence level. Results obtained from HWILTs and live test events can then be used to validate the models. This provides a cost effective way to verify interoperability of Service systems before they are fielded to operational units. The use of M&S in FoS T&E will be in three basic areas: pre-test planning and prediction, post-test validation activities, and Theater-level analysis. The primary simulations for use in the FoS T&E program will be the Extended Air Defense Testbed (EADTB) and the Extended Air Defense Simulation (EADSIM).

1.1 TMD Family of Systems (FoS)

The TMD FoS consists of Service weapon systems and C2 centers that are defined in the BMDO's core

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program. Also included are upgrades to Service weapon systems and C2 centers. TMD FoS testing is being conducted by the TMD Systems Engineering and Integration (SE&I) Contractor Team.

1.2 FoS T&E Methods

The FoS T&E program is designed to build on the individual Service development programs to include Service T&E activities, as shown in Figure 1-1. The purpose of joint T&E is to focus on requirements verification to ensure the successful integration and interoperability of the independently developed TMD C2 centers, sensors, and weapon systems into a cohesive FoS. The FoS T&E program is predicated on three test methods: live test events; HWILTs, which involve the actual tactical systems; and Models and Simulations.

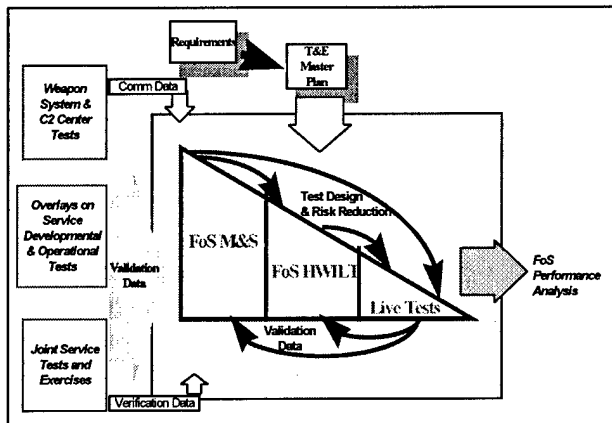


Figure 1 -1. TMD T&E FoS Test Methods

The wedge in Figure 1-2 indicates that as fidelity increases, the number of tests or trials that can be run decreases. Live fire test events provide the highest level of fidelity, but due to their high cost, very few events can be run. Live events also lack repeatable results due to the large number of testing variables. FoS T&E relies on all three methods with data being exchanged between them. The FoS T&E strategy will employ the "model-test-model" paradigm for better prediction and M&S assessment capability. Through this approach, M&S tools will first be used in test planning and prediction, then the test event will be executed, and finally, test event data is used for M&S validation and improvement.

While M&S provides the community the ability to control and test to significantly varying test conditions, a question of confidence in the results will always remain. A bridge between M&S and live tests is the HWILT. The Theater Missile Defense System Exerciser (TMDSE) provides the ability to test tactical hardware with simulated threats to

evaluate the FoS during the Service systems' development. "The TMDSE is a real-time, geographically distributed, hardware-in-the-loop test capability that stimulates actual tactical missile systems and early warning systems"¹⁶. HWILT events can test tactical hardware with a variety of threats in any simulated theater.

In the conduct of FoS T&E, both M&S and HWILTs are used for risk mitigation of live test events by providing a characterization of the events expected during the live test. A major objective of all live testing is to collect data that can be used to validate both M&S and HWILT tools and to support the accreditation of these tools. In addition, both M&S and HWILTs provide the opportunity to extend live test results to assess FoS performance in scenarios and environments that are not possible during live testing.

1.3 Characteristics of Models and Simulations

M&S are used in FoS assessments for few-on few to many-on-many engagements and large theater architectures. M&S are the only tools that can be used to examine Theater-wide FoS issues in scenarios that include a realistic number of threats expected under tactical conditions (including stressing environments). This realistic representation of the threat is based on the BMDO Directorate of Threats and Countermeasures (BMDO/DTC) approved data.

Key M&S characteristics include the:

- a) Ability to represent a variety of weapons and radar systems at a high level of fidelity
- b) Availability of a wide range of high fidelity threats and environments
- c) Ability to examine performance under a large number of threats and a heavily loaded communication networks at a high level of fidelity
- d) Ability to assess TMD systems in Theater-level tactical deployments
- e) Use of simulated TMD systems and supporting communication networks
- f) Ability to create a scenario anywhere in the world

There are several advantages and limitations to using models and simulations:

Advantages:

- Permits controlled experimentation and repeatability of experiment conditions
- Permits time compression

- Permits sensitivity analysis by manipulation of input variables
- Does not disturb the real system.
- Ability to gain statistical confidence through Monte Carlo runs
- Lowest cost method of collecting data

Limitations:

- Availability and accuracy of platform performance characteristics.
- Cannot account for the decisions made by the tactical system operators in a live tactical environment
- Simple human decision modeling
- Limited operator involvement
- Extensive set-up time may be encountered and model parameters may be difficult to initialize. These may require extensive time in collection, analysis, and interpretation.
- Level of validation of the M&S using real-world data and subsequent user accreditation.
- Lower confidence results

Given the aforementioned advantages and limitations, M&S is a vital part of a complete T&E program when used in conjunction with HWILTs and live events. Incorporating M&S into the T&E program allows the test program to be better focused on the critical areas for evaluation. The early use of M&S in the system analysis, definition of requirements, and system test and evaluation provides for a more comprehensive system engineering process.

2. STRATEGY FOR INTEGRATING M&S INTO FoS T&E

Models and simulations will be incorporated into the TMD FoS T&E program using the principles of the Simulation, Test and Evaluation Process (STEP)⁸ and will conform to DoD Directive 5000.59-P.

2.1 Incorporation Of M&S Into FoS T&E

FoS T&E will be conducted to demonstrate program development and system performance throughout the life cycle of the FoS. FoS capability will evolve through a series of increments, with each increment serving as the basis for the next. Analysis will be the primary evaluation tool in the early phase of each increment. Simulations will be used in the analysis to evaluate design tradeoffs and candidate models will be identified for use in further analysis. M&S will be used in pre-test planning and prediction as well as post-test analysis. FoS level exercises will be conducted to assess the interoperability and performance of the FoS. Based on data gathered from the live events, M&S will be used to assist in model V&V activities. This paradigm will be repeated throughout the development efforts. This is the "model-test-model" approach that has become STEP.

The STEP approach integrates the use of M&S with test events, each depending on the other, to add value to the T&E process. M&S are part of a strategy to provide information by predicting test results, by exploring performance in the testable realm, and by extrapolating performance in the non-testable realm. Tests are used to provide data from the real world regarding situations and environments and permit an assessment of the attainment of technical performance specifications and system maturity⁸. Figure 2-1 depicts an example of how M&S will be integrated into live FoS T&E events and illustrates the model-test-model approach being used.

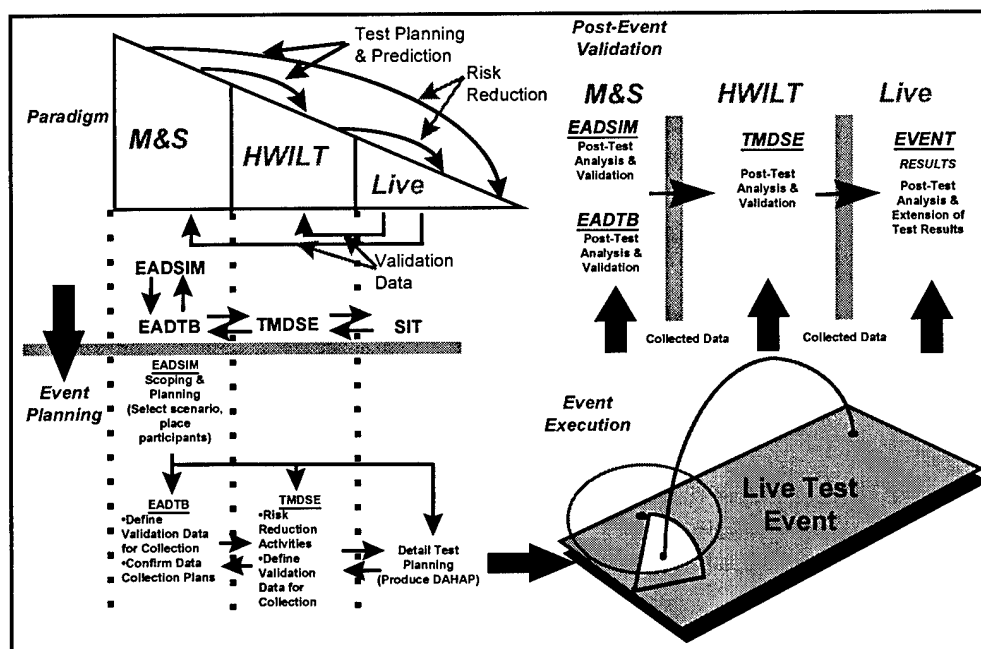


Figure 2-1. M&S Coupled to Live Test Events.

In this example, input data needed to accurately represent the systems in EADTB, EADSIM and TMDSE will be identified in pre-event modeling activities. This data will be identified for collection during the live event and will be used in post-event simulation runs to assist with model validation and with post-test analysis. Data collected from the event will be used to satisfy the allocated Measures Of Performance (MOPs).

M&S will be used in three major areas for the FoS T&E program: pre-test planning and prediction, post-test analysis and validation activities, and theater-level FoS analysis and assessment. The near-term focus for T&E M&S events will be to establish the necessary procedures and coordination needed to effectively use the M&S tools to address FoS T&E requirements. A primary activity associated with the near-term use of M&S will be to use data from other T&E events to begin validation of the M&S tools that will support the FoS T&E program.

The primary uses for M&S will be:

- a. Test Planning and Prediction
 - Support scenario selection and development
 - Prediction of test results
 - Confirmation of data collection plans and dry run data analysis plans
 - Identify additional validation data for collection
- b. Post-event M&S activities

- Compliment HWILTs, System Integration Tests (SITs) and other live events
- Compare M&S results with test results
- Analyze test anomalies
- Assist with M&S validation activities
- c. Theater-level performance of the FoS against large numbers of threats
 - many-on-many scenarios in a variety of theaters
 - FoS performance under peak network loading
 - network performance evaluation under full loading conditions
 - Performance of the FoS versus the same systems operating autonomously
 - Battle Management/Command, Control and Communications (BM/C3) effectiveness at the theater and control levels
 - Evaluation of timelines required in information flow for cueing, engagement coordination, kill assessment, etc.
 - Extension of live test activities (number of threats/different environments)

2.2 General M&S Strategy

The general process for using M&S in the FoS T&E program is illustrated in Figure 2-2. This process consists of: 1) evaluating and selecting M&S tools based on the T&E requirements, 2) using the M&S tools in support of T&E events, 3) using data from

T&E events to support V&V activities and 4) to provide feedback to the test planning process. The steps required to execute this process are listed below.

1. Evaluation and selection of appropriate M&S tools based on requirements. This process will continue throughout the life of the T&E program as the current M&S tools evolve and as new tools become available.
2. Establish the hierarchical relationship between the chosen M&S tools.
3. Establish the linkage between the chosen M&S tools and the T&E requirements/objectives. MOPs will be allocated to M&S events and M&S tools will be chosen that can provide the data to support the assessment of those MOPs.
4. Tie into and leverage off analysis results. Through this process, T&E is involved in the requirements definition phases and can utilize the results to gain a full understanding of the system requirements and gain insight into the performance and utilization of the M&S tools. This will aid in the development of the model hierarchy, the evaluation of the tools, the types and content of tool input and output data, analysis of the output data, and suggestions for improvements in the tools.
5. Verification and calibration of the selected M&S tools through the use of data from live T&E events as well as data from MDAP models. This process is necessary to gain confidence in the tools and to ensure continuous improvements in the models.
6. Use of M&S in pre-test activities, post-test activities, and Theater-level analysis.
7. Use of data and results from M&S and other T&E events to revise test plans and requirements and to provide feedback to model developers.
8. Population of a data repository to provide the community with timely, verified, and validated data for use in other programs.
9. Creation and population of data commonality matrices for the purposes of maintaining a record of data that is common between the various M&S tools and live events.

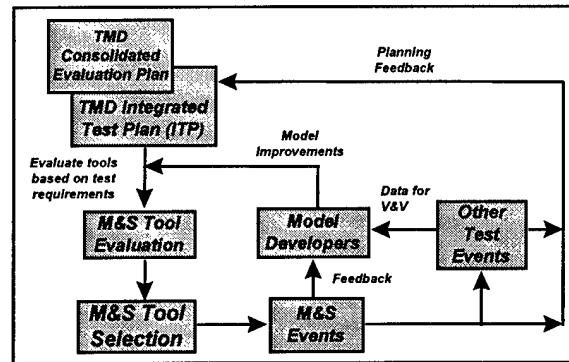


Figure 2-2. TMD FoS T&E M&S Process.

Through the implementation of the above processes, the use of M&S in the FoS T&E program becomes one piece of a larger process in which M&S is used throughout the systems engineering cycle. The coordinated use of M&S in the areas of analysis, engineering, requirements definition, as well as system test and evaluation provides a more robust and efficient process for the development and evaluation of the TMD Family of Systems. The most important components of this system engineering approach are a detailed plan for the use of M&S throughout the process, early selection and evaluation of the tools to be used, ensuring the credibility of the tools to be used, using the resulting data to improve the tools, and ensuring the flow of data to all key players in the process. Early and iterative use of M&S in the systems engineering process can aid in the identification of critical test issues and the allocation of MOPs to particular test events. M&S can also be used to design more effective T&E events, extrapolate the results from live test events, and to better understand the aspects of system performance observed during test events. This process embodies the spirit of the STEP process as well as the intent of DoD 5000.2-R⁸.

3. IMPLEMENTATION OF THE M&S STRATEGY

The implementation and application of these processes will integrate all applicable elements of the STEP process into the FoS T&E program. The implementation of this strategy will aid in the development of an efficient process for the analysis, test and evaluation of the FoS.

3.1 M&S Tool Selection and Hierarchy

The first step in the M&S process is to identify those M&S tools that can be used to satisfy the T&E objectives and requirements that are specified in the system requirement documentation. Once the M&S

tools have been identified, a hierarchy must be established. In this hierarchy, the relationship or affinity of these models to each other and the flow or exchange of data between the tools is identified. The M&S hierarchy consists of four categories as shown in Figure 3-1.

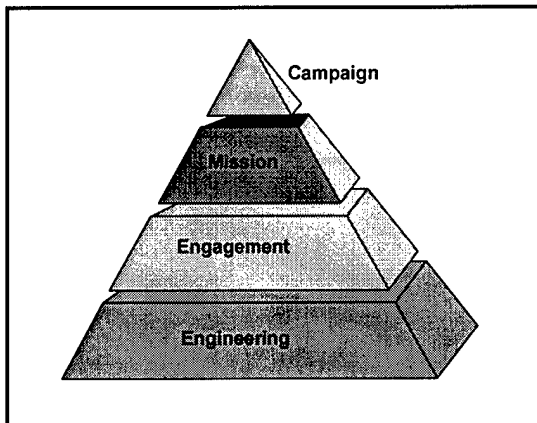


Figure 3-1. Modeling and Simulation Hierarchy.

Engineering/Phenomenology Models. These models deal with the actual physics involved with specific system functions such as radar cross section, signature, lethality, and debris⁹.

Engagement Models. These models usually deal with specific weapons systems and their components. These high fidelity models are used by the MDAPS and deal with such issues as end-game lethality⁹.

Mission-Level Models. These simulations are more aggregated and may vary in fidelity from high to low. The simulations contain models of various weapons systems and components and can be used to explore few-on-few to many-on-many engagements between a number of systems⁹.

Campaign-Level Models. These simulations are usually highly aggregated and have low fidelity representations of numerous systems. They are typically used to provide insight into a system's

contribution to force effectiveness and to study force structures and logistical requirements⁹.

The hierarchy of M&S tools is established to define the flow of data. Models at the bottom (engineering/phenomenology) provide data to models at the next level (engagement) which, in turn, provide data for the mission level models which feed the campaign level models. The models at the lower level address very specific issues. Each higher level of the hierarchy addresses larger issues, but usually at less fidelity or detail. The hierarchy is used to establish an affinity diagram such as the one shown in Figure 3-2. The purpose of the affinity diagram is to define how data flows between M&S tools and test events.

The legend for this figure as well as Figure 3-4 is shown in Figure 3-3. Figure 3-2 shows the hierarchical relationship of the models and simulations used in TMD FoS. The diagram shown here is notional and shown at a low level of detail. Since a thorough understanding of this data flow is critical to ensuring the success in the incorporation of M&S into the T&E program, more detail would need to be added to this affinity chart. Even at a low level of detail, however, the analyst can still gain some insight as to how various M&S tools can be linked together to achieve the established T&E goals and objectives. This figure was designed to provide an overall view of the simulations being used, or that could be used, and how they relate to each other as well as to FoS T&E events. The chart can be used to aid the analyst in choosing models for a particular study or T&E event. However, the more detail contained in the M&S affinity diagram the more useful it will be in defining how the M&S tools will be applied. The T&E program will typically employ models at various levels of fidelity depending on the issue being addressed.

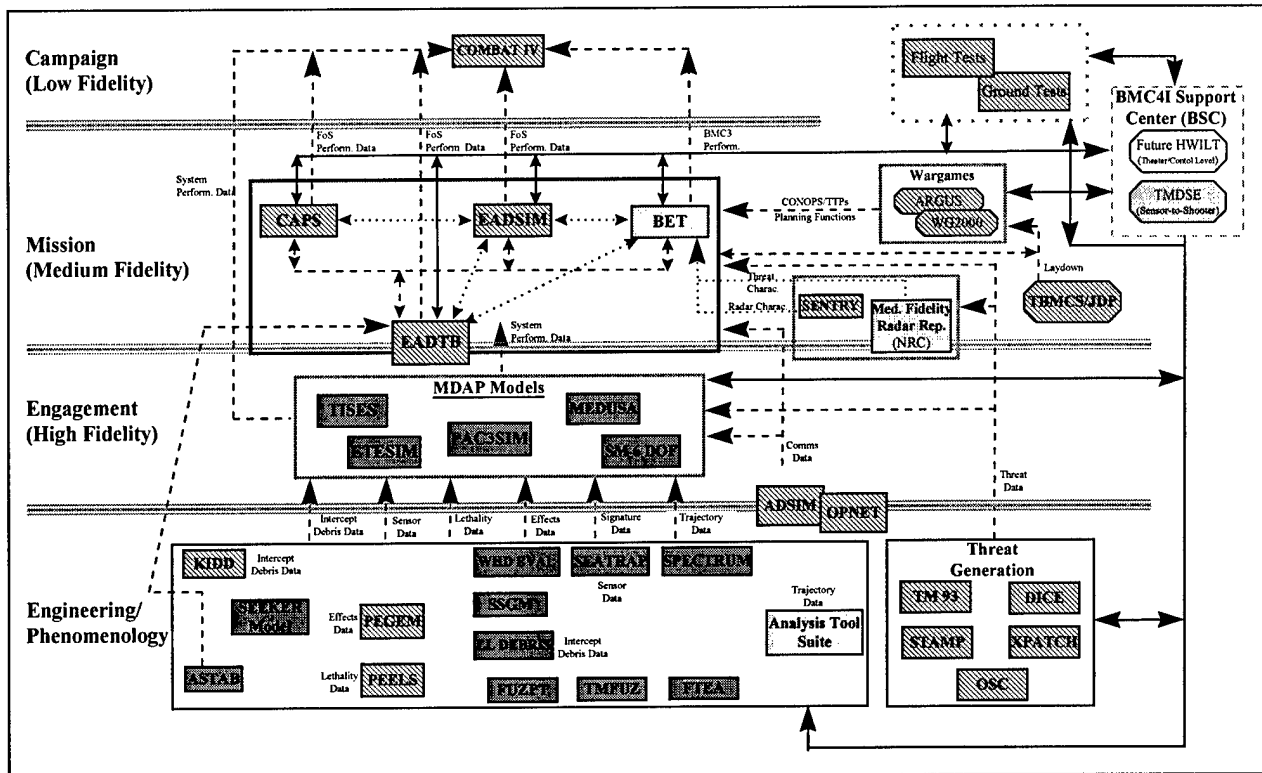


Figure 3-2. TMD FoS M&S Hierarchy and Affinity.

It should be noted that the data flow between models shown here is in "general terms." The specific data that can be utilized between models and simulations is situation or scenario specific and will change based on the types of questions to be answered using the model or simulation. The purpose of showing the "general" data flow is to give the analyst an idea of the type(s) of data that each model/simulation can produce and which models/simulations can accept that type of data and confidence that the results will address the questions with some degree of fidelity.

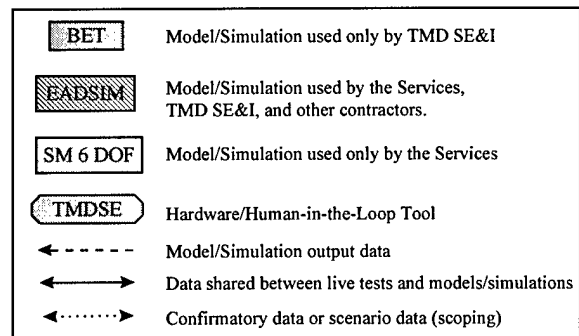


Figure 3-3. Legend for Figures 3-2 and 3-4.

In Figure 3-4, the hierarchy is scoped down to highlight the models and simulations primarily used in TMD FoS T&E. The figure shows how the M&S tools relate to each other as well as how they relate to T&E events. The figure also depicts how data from live events is used for validation of the models and where the M&S are used for test planning and risk reduction activities.

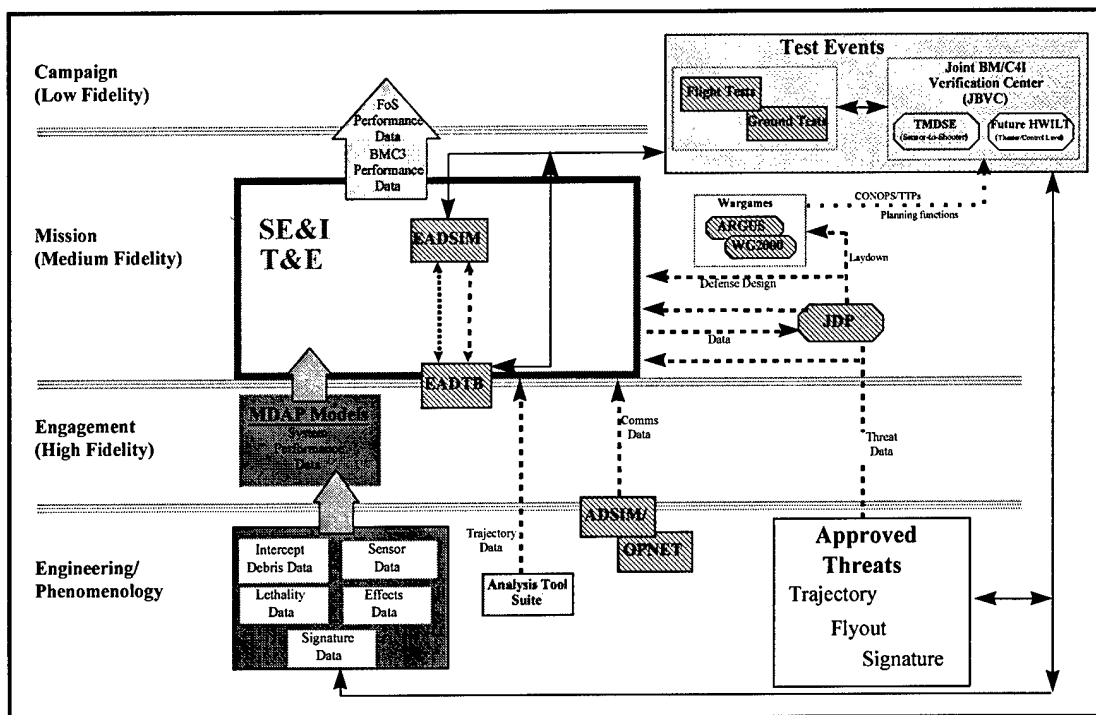


Figure 3-4. SE&I M&S Relationships for TMD FoS.

3.2 Linkage To FoS T&E Requirements

Test and evaluation requirements must be linked to the M&S tools to be used. The TMD FoS T&E requirements span three functional areas: Planning (JPN), Coordination (JDN), and Execution (JCTN). M&S tools were selected based upon their ability to address issues in one or more of these functional areas. A combination of tools is needed in order to span the requirements in all three areas.

Figure 3-5 shows the functional areas covered by the various test methods (Execution, Coordination and

Planning) as well as the primary M&S tools. Also indicated in this figure is the flow of data that occurs in order to link the various test methods. This linkage is needed to provide for complete verification of the requirements, which may rely on more than one test method. Through this approach of linking various M&S tools, HWILTs, and live events, all TMD FoS T&E requirements can be adequately addressed.

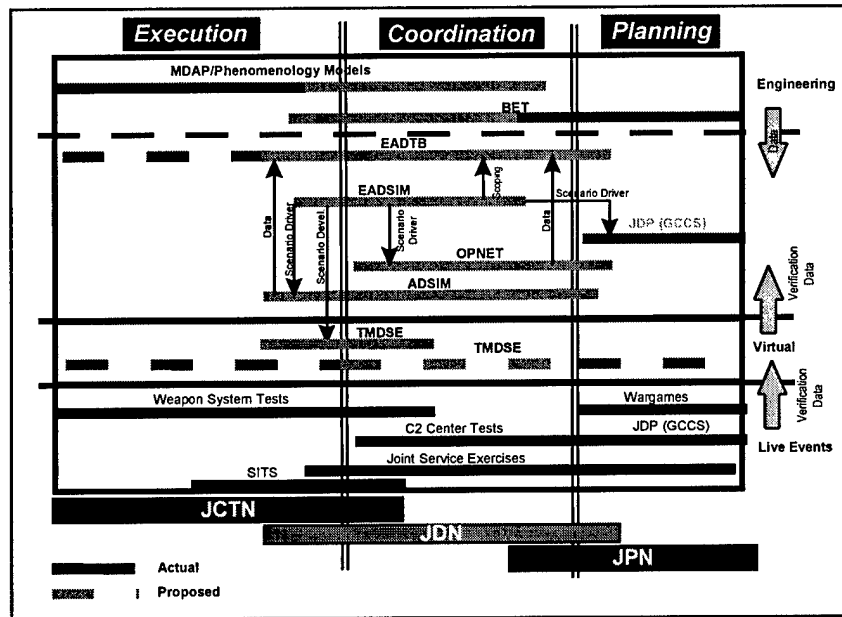


Figure 3-5. M&S For TMD FoS T&E.

3.3 Relationship Between The Analysis And T&E Functions

The use of M&S for FoS evaluation includes more than T&E events. M&S are integrated into the T&E process to support a comprehensive evaluation strategy throughout the life-cycle of the system. The use of M&S early in the requirement definition phase is important in achieving this means. Thus, the use of M&S spans the analysis and T&E communities and their use should be coordinated and complimentary.

STEP can contribute to refining the TMD Capstone Requirements Document (CRD) requirements. Using M&S to support sensitivity analyses can identify performance drivers and aid in determining critical technical and operational issues. Through analysis, M&S tools can be used to identify and refine Measures Of Effectiveness (MOEs) and MOPs and to establish objective and threshold criteria to be used in both the analysis and T&E efforts⁸. M&S are critical to the complete evaluation of the system through early analysis as well as test and evaluation. The use of M&S throughout the process of requirements definition, analysis and T&E provides the foundation needed to establish a comprehensive system evaluation strategy with clearly defined, measurable parameters with associated quantifiable evaluation criteria.

Figure 3-6 shows how the analysis and T&E functions work together to form a comprehensive evaluation plan for the TMD FoS. Analysis is used

to transform the top level requirements from the CRD into system-level requirements for the SRD. This analysis also produces Technical Performance Measures (TPMs) for evaluation of the system. The SRD requirements are then verified through analysis, test and evaluation, or a combination of analysis and testing using the TPMs. If the requirement is satisfied, then the data is stored in a requirements verification matrix, which contains the requirements and their traceability to the CRD as well as the data that supports the satisfaction of that requirement. If the requirement is not satisfied, then it must be referred to further testing and/or analysis. In some cases, it may be determined that the requirement cannot be met. If this happens, further analysis will be required to determine the effect of the requirement not being met on the system as well as the impact on other requirements.

The ability to trace evaluation results to requirements is vital to demonstrating the degree to which the system performance satisfies the requirements. The iterative nature of STEP enables the linking of performance measures and derived parameters back to the operational requirements⁸.

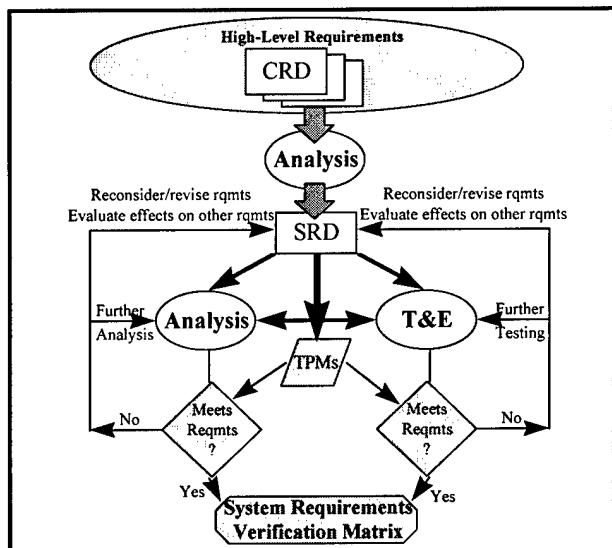


Figure 3-6. Requirements Verification Process.

3.4 M&S Tool Verification, Validation And Accreditation (VV&A)

One of the most important aspects of STEP is the verification, validation and accreditation (VV&A) of the M&S tools to be used.

The STEP approach involves integrating the data from laboratory and field tests to validate models and simulations as the system matures⁸. This process will result in a more robust set of M&S tools that gain credibility as the evaluation program progresses. A high degree of confidence and credibility in the models is required for their use for T&E.

Accreditation is usually the result of a thorough V&V process. Although the SE&I Team does not have the responsibility for planning and conducting V&V on any of the models being used, both the analysis and T&E efforts have a responsibility to ensure that the M&S tools being used produce credible results for the intended uses. This responsibility includes tracking the results of V&V activities being performed and collecting data for comparison with data from other accredited models or applicable test events.

For validation purposes, a model or simulation can be partitioned by its inputs, outputs, or by the structure of the model itself. Two widely accepted domains for validation include "output validation" and "structural validation."¹⁰

Output validation is the most credible form and should be conducted at the full model level to the extent possible¹⁰. When this is not possible, the model should be decomposed and output validation conducted for the components. Structural validation

should be accomplished for those aspects of the model critical to the model's intended use¹⁰.

V&V requires both quantitative and qualitative assessments. Quantitative assessments should be used to the maximum extent possible. Activities need to be focused on the specific areas or questions the model is going to be used to address. These activities should provide for a systematic examination of the model and should portray the capabilities and limitations of the model in regard to the questions the model will be used to answer. This is particularly true in the case of the FoS program. Due to the number of models used either directly or indirectly by the SE&I team, complete V&V of all models will not be possible. Most of the models will be accredited by their respective development agencies' use of independent assessors, possibly with the use of data obtained through the FoS T&E program.

The general process for V&V activities will be to use data from live test events and exercises for comparison with M&S output data where applicable. Most of the test data will not contribute significantly to validation of the force-on-force models with the exception of the EADTB System Specific Representations (SSRs). For the most part, the test data will be provided to the developers for V&V of the engineering and MDAP models. Credibility in the force-on-force models will be gained by using the output from the engineering and MDAP models as input to the force-on-force models.

3.4.1 Output Validation

In general, output validation contributes the most convincing evidence in establishing the credibility of a model¹⁰. This process involves determining the extent to which the model or simulation output represents the significant features of real world systems and events. Output validation involves collecting data from live events such as system integration tests and joint exercises and comparing them with the output of the model¹⁰. In the case of the MDAP and engineering-level models, this process will be relatively straight forward. During the test planning phase, data will be identified for collection that can be matched with the output data from the various models. This will include the matching of MOEs and MOPs that can be associated with both test data and model output.

For EADSIM and EADTB, this process will be more difficult. These force-on-force models involve a complex interaction of systems and the environment. Replicating the scenario in terms of the locations of the systems and the scripted events is possible, but

replicating the interactions of the systems and the decisions of the human operators is far more difficult. It is also impossible to accurately model the effects of the environment on the individual events. When using live exercises for comparison purposes, care must be taken to analyze only those areas that can be tightly controlled, such as the individual system models, network traffic, etc. More generalized comparisons can be made in terms of the outcomes of engagements, the number of TBMs destroyed, etc.

In addition to the quantitative validation in which measurable and observable outputs are studied, qualitative assessments are also important. A simulation such as EADTB is too large and complex to be verified solely by quantitative means. Therefore, it is imperative to rely on the opinions of the operational and technical subject matter experts. This "face validation" would include obtaining the opinions of these experts on the model areas that are of critical interest to the FoS.¹⁰

It is extremely important that the observations and measurements made in the real world are compatible with the model output and are applicable to the areas of interest the model will be used to study.

3.4.2 Structural Validation

EADTB is a very complex simulation consisting of many different models. Output validation of such a simulation is extremely difficult, therefore, structural validation very important. Structural validation deals with an a priori examination of the model input data, the basic principles of the model, and the model's assumptions to determine the degree to which they are complete, logical, consistent and reasonable for the intended uses of the model¹⁰. Structural validation can aid in developing confidence in the model results by demonstrating the model's internal integrity. Structural validation determines the degree to which the model input data (e.g., scenarios, missions, and data bases) and the model (e.g., assumptions, logic, and parameters) represent the real world.

For EADTB, most of this is being accomplished through the use of the certified SSRs in early studies. Through these studies and by working with the SSR developers, a good understanding of the model, its data and its assumptions can be gained. These studies are conducted on very limited areas and the results are compared with data from MDAP models, Military Standards, test data, and the experience of operational and technical subject matter experts.

EADTB will be anchored to and will receive data from a number of MDAP and/or engineering level models. Ensuring the validation of these feeder

models will also aid in the credibility of EADTB. A majority of the structural validation will be accomplished during the early studies and analyses.

Sensitivity analysis is another important aspect of V&V. Sensitivity analysis should be conducted on the model and its decomposed parts and can be used to check for responses to various inputs and to check for marginal break points and special limiting values¹⁰. Sensitivity analysis is useful in gaining a better understanding of how the model works and to help identify errors in the model structure or code. When coupled with the comparative validation process, the sensitivity analysis can help ensure that the models sensitivities are representative of the real world. This can be accomplished during the analysis conducted in support of the System Requirements Document (SRD).

A thorough understanding of the model including its sensitivities is very important if the model is to be used for T&E. The effects of various inputs on the specific outputs of interest must be explored and well understood.

The most important V&V activity is the documentation of data and results. All relevant data collected from T&E events will archived be and a matrix will be developed that shows the relationship between test data and the M&S tools from both an input and output perspective.

3.5 M&S Implementation In TMD FoS T&E

Once the M&S tools have been analyzed for their contribution to FoS T&E assessments and a level of confidence has been gained in the data produced by the tools, they can be implemented into the T&E effort. T&E activities delegated to M&S tools include pre- and post-test activities and theater level analysis.

3.5.1 Pre-Test Activities

The use of M&S in pre-test activities includes supporting the selection and development of scenarios for BMDO-controlled test events. These events primarily include System Integration Tests (SITs) and HWILTs. Pre-test M&S events will have the following objectives:

- ensure that the planned Red Force scenario and Blue force laydown will meet the test requirements
- ensure test objectives can be met
- focus the test on critical aspects of the test objectives
- identify scenarios that will contribute the most to the test objectives

- determine the most efficient use of test resources
- characterize the test activities and predict test results
- data collection planning, i.e., identify sources of data to support test objectives and model validation activities
- identify potential problems (procedural, test architecture, data collection, data analysis)

Most of these objectives will be accomplished through "dry runs" of the planned test event prior to the event in sufficient lead-time to influence test documentation with predicted results. Pre-test M&S activities reduce the potential risks associated with execution of the test event and provide confidence in the achievement of test objectives, which is important due to the high cost and in-frequency of these events. M&S could also be used to create scenarios that will specifically test FoS interoperability and performance issues. These scenarios can then be utilized in HWILTs and other T&E events.

EADSIM and EADTB are used for pre-running HWILT events. Each has the ability to rapidly model all the participants in the event as well as model the region using Digital Terrain Elevation Data (DTED). As EADTB matures to incorporate a full suite of Service participants as well as more defined threat systems, it will become the tool of choice for pre-running HWILTs. Using M&S to model the scenario allows the developer the ability to change the scenario based on simulated outcomes. This ensures that the final scenario will test the FoS to accomplish the required test objectives.

For live exercises, M&S are used to determine the sequence of events from launch to impact/intercept. These pre-test simulation runs provide the ability to mitigate risk by visualizing the scenario prior to a costly System Integration Test (SIT) or other live test event. Live events also provide a means to obtain data for use in M&S verification and validation activities.

3.5.2 Post-Test Activities

Models and simulations benefit the tester by giving him a means with which to identify and analyze anomalies that occurred during the test. The simulations can also be used to play "what if" games by varying test parameters and comparing the simulation results with the actual test results. An examples would be assessing the performance of the FoS versus the same systems operating autonomously or assisting in the investigation of what may have gone wrong in the test and provide possible solutions to be incorporated into the planning of future tests.

Post-test activities also includes the comparison of the simulation outputs with the actual test results. Post- event simulation runs are used to compare the simulation output data to the actual event data. The model is then modified to more accurately represent the "real world". Test data would be provided to the model developers for use in model validation activities. Through this process, testers gain confidence in the M&S tools for their use in future test studies.. Post-test analysis will also aid in confirming the tool's ability to support T&E and to possibly identify new ways in which the tool can be used. This analysis will help identify shortcomings in the model and possible areas for enhancement. Variations in the results between M&S and live events will be reported to BMDO who will feed the information back to the model developers. M&S tools may also be used to help explore the cause of differences between predicted and actual test results. Whenever possible, M&S data will be collected in support of the same MOPs for which live data was collected. This will aid the V&V process by providing common data points for comparison.

3.5.3 Theater-Level Analysis

M&S are used in FoS T&E to extend assessments from few-on-few to many-on-many engagements and large theater architectures. M&S are the only tools that can be used to examine Theater-wide FoS issues in scenarios that include the number of threats that can be expected under tactical conditions, as well as providing realistic representations of DIA approved threats. This method can be used to examine theater communications networks under the loading associated with projected threat levels for both TBMs and air breathing objects. Examining the networks under maximum loading provides the opportunity to examine effects on FoS capabilities resulting from changes in the timelines for critical information flow due to changes in message update rates, as well as the amount of information the system receives.

Theater-level simulations can also be used to compare the protection effectiveness of the FoS as compared to the same systems operating autonomously. Once timelines for the transfer of information have been established through tests and exercises, the change in effectiveness of attack operations and passive defense can be analyzed. Theater level simulations provide an opportunity to identify potential integration or interoperability issues that may be associated with the deployment of a theater-wide FoS. Once these issues have been identified and analyzed, system and test requirements can be modified to address the problems.

Theater-level analysis will be accomplished, in part, by the use of simulations to extend the results of few-on-few live test events to many-on-many scenarios. The primary role of T&E in this analysis will be to provide the actual test data to aid in the conduct of FoS performance analysis by the systems engineer.

3.6 Data Feedback Plan

The flow of data in the evaluation process is critical. Data flow needs to be maintained between the various M&S tools to provide inputs and feedback. Data from the engineering and engagement level models will be used as inputs and validation data for the mission and campaign level models. Outputs from the mission and campaign-level models will be used in the planning of test events, extension of test results, and will be compared with the data from the engineering and engagement level models for validation activities. Data from live test events will support model validation activities and will be used as feedback to the model developers. This general process is illustrated in Figure 4-7.

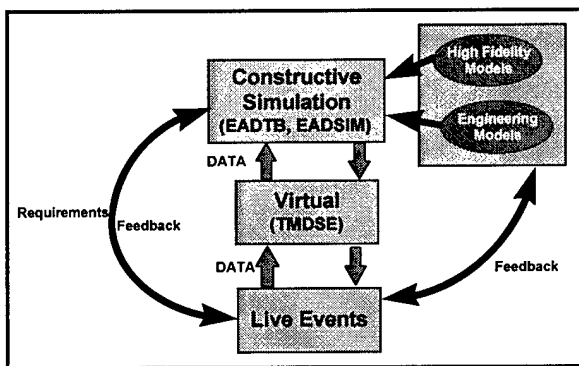


Figure 3-7. General Data Flow Between M&S and Test Events.

Maintaining the exchange of data and information between the M&S community and T&E is critical to the success of the FoS T&E M&S efforts. According to STEP, feedback from tests to simulations is not only required for VV&A, but also to allow progressive improvement in the M&S⁸. M&S developers need to be represented in the test planning process so that they may gain an understanding of the event and to identify data that can be collected for model inputs and in support of model validation. A matrix of common data between the various models and simulations and test events should be established to aid in this process.

It is also important to maintain a flow of data and information between the FoS analysis and T&E efforts. Analysis results may uncover problems or

shortcomings with the models that may need to be addressed prior to their use for T&E. Results from the analysis may also be used to quantify testing parameters and to aid in the identification of MOPs and data requirements that can be satisfied with the various M&S tools. On the other hand, results from T&E events may reveal areas that will require further analysis or uncover requirements that may need to be revised or added. These are only a few examples of the benefits that can be gained from the interaction between the T&E and Analysis functions. In order to ensure that this interaction occurs, representatives from T&E are updated on the progress of the analysis and often participate in the studies. Likewise, members from the analysis team will assist in the execution of the T&E M&S events. This close interaction will not only enhance the flow of information between the groups, but will also help to leverage valuable resources.

3.6.1 Model And Simulation Data Center

All test and M&S output data needs to be stored and maintained for future reference. Data from FoS T&E events should be submitted to the BMDO Simulation Support Center (BMD SSC), which is part of the Defense Modeling and Simulation Office (DMSO) Modeling and Simulation Resource Repository (MSRR). The BMD SSC is a data archive, access, management, and distribution system for science and technical data/information. The BMDSSC M&S Repository has the capability to store and provide access to TMD and NMD test and exercise data, such as SITS, HWIL, flight tests; or to provide pointers to where that data is stored.

The MSRR is a collection of M&S resources. MSRR Resources include models, simulations, object models, Conceptual Models of the Mission Space (CMMS), algorithms, instance databases, data sets, data standardization and administration products, documents, tools and utilities.

Both of these programs are critical to the successful implementation of M&S in any large scale effort as they provide valuable M&S resources and maintain data that can be used for V&V, model input, or future reference.

3.6.2 Data Commonality Matrices

The purpose of the Data Commonality Matrices would be to identify common data requirements between FoS T&E events and the M&S tools. Data obtained from T&E events could be used either as input for M&S or as data for verification/validation activities. In order for this process to occur, the test

events that can provide relevant M&S data must be identified and the relevant data extracted.

The Data Commonality Matrices would list each type of FoS T&E event and the FoS data that is expected from the event. The data, as it relates to FoS test objectives and requirements, will be matched with the M&S level that might benefit from that data. Additional data may also be obtained from these tests if proper planning is used to identify the useful data and prepare for the data collection.

The FoS T&E events offer a vast amount of data for use in BMDO models and simulations. This data can be used as either input for routine simulation runs, such as the scenario data obtained from the CINC Assessments, or for model verification/validation, such as the system data obtained from SITs or MDAP tests. Although most of the FoS test data primarily benefits the Engineering or Engagement level models and the EADTB SSRs, some data may also be used by the Theater level models either directly or indirectly. Once test data has been used to verify a system in an Engineering or Engagement level model, that information can then be used to validate the Theater level model's representation of that system.

Through the use of these matrices, the model developers would have an idea of which T&E events are likely to provide data of interest to their specific model or purpose. The matrices would also aid the T&E team in selecting models to address specific test objectives.

4. CONCLUSIONS

M&S will be an important tool in conducting FoS interoperability assessments. Live tests are normally conducted when conditions are perfect and ensures the most successful outcome possible. M&S tools will allow for the testing of the FoS when conditions are less favorable and more representative of actual war time situations. Using M&S with the actual tactical hardware provides higher confidence that these systems when deployed to the theater will coexist in an interoperable environment among all Service weapons and C2 systems. Future tests will be conducted on an event-driven basis as weapon system and C2 center capability becomes available and requires testing to ensure requirements can be met.

It is important that each test continue to provide information that will enhance future tests. Whether it is using live data to increase the fidelity of M&S or tools predicting live test objectives, M&S will play a vital role in making sure that the FoS is up to the

standards necessary to defend any asset anywhere in the world when the time comes. It is also very important for BMDO to continue the development of a core set of models and simulations and to support the development, enhancement and validation of those core M&S tools

The implementation of M&S into the T&E program will provide the opportunity to conduct tests and verify requirements that would otherwise be too costly or difficult to accomplish. Identifying and documenting procedures from STEP will ensure the "model-test-model" paradigm will lead to the successful integration of independently developed TMD weapon systems and C2 centers into a cohesive FoS prior to deployment of the systems. It is also important that the T&E, M&S, and analysis communities work closely together to interchange and compliment data to support M&S development, enhancement and validation. This relationship would also enable more effective use of M&S throughout the development and testing of the system.

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